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Effect of Nano Powder on Mechanical and Physical Properties of Glass Fiber Reinforced Epoxy Composite

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Abstract

Fiber reinforced polymer composite is an important material for structural application. The diversified application of FRP composite has taken center of attraction for interdisciplinary research. However, improvements on mechanical properties of this class of materials are still under research for different applications. In this paper we have modified the epoxy matrix by Al_2O_3, SiO_2 and TiO_2 nano particles in glass fiber/epoxy composite to improve the mechanical and physical properties. The composites are fabricated by hand lay-up method. It is observed that mechanical properties like flexural strength, hardness are more in case of SiO_2 modified epoxy composite compare to other nano modifiers, were physical properties like density, water absorption are more in case of TiO_2 modified epoxy composite. This may be because of smaller particle size of silica compare to others.

Key word: *Density, Water absorption, Hardness, Flexural Strength, Glass fibers, Composites.*

1. Introduction

Development of new composite materials or modification of existing composite material is the real challenge for most of the materials engineers. Epoxy base matrix composite has tremendous potential to substitute the traditional metallic materials. Polymer matrix modification is one of the approaches to develop new class of polymer structural materials. This modification can be done by addition of different ceramic powders of different sizes to achieve the required mechanical properties. McGrath et al. (2008) studied the effect of alumina powder in epoxy on mechanical properties. They found that there is a little effect on change in particle size, shape and size distribution on final properties. However the resin crosslink density and filler loading were the most critical variable, which may change all properties [1]. L.Merad.et.al, have study the mechanical properties of epoxy resin reinforced with TiO_2 nanoparticles. These nanoparticle are 21nm in diameter and volume fraction (o.5, 1, 5 and 20%).The results shown that the mechanical properties like hardness and tensile strength higher than net epoxy and increased with increase addition of TiO_2 nanoparticles [2].

Ikram .et. al, have studied mechanical properties of micro and nano TiO_2/ epoxy composites, with epoxy volume fraction (1,2,3,4,5,6,7,10,15,20) of microparticles TiO_2 (50 µm) and nanoparticle TiO_2 (50nm) the flexural strength, Young modulus and fracture toughness of nanocomposites were increased at low volume fraction (less than 7 vol%). At higher volume fraction both flexural strength and fracture toughness decrease while Young modulus still higher than that of epoxy. The flexural strength and fracture toughness of epoxy-microcomposites decreases with increasing the volume fraction of TiO_2 microparticles specially at high volume fraction while Young modulus increases with increasing the volume fraction [3].

Dr.Falak O.Abas,Raghad O.Abas and Sarmad I.

Ibrahim have studied the properties and behavior of particles on (glass, carbon, and Kevlar fiber) reinforced polyester composites. The effect of alumina (Al_2O_3) and silicon carbide (SiC) particles ceramic polyester composites are investigated at different additive ratios as (0.2, 0.4, 0.6, 0.8, 1.0%) volume fraction. Comparative analysis show that the bending distortion, hardness, and impact resistance are affected by the type and content of filler particles, where both impact and Hardness is increased with increasing volume fraction specially in case of (0.5%) volume fraction for both filler particles and decreased for bending distortion specially in case of glass fiber/ polyester at (0.5%) volume fraction for both filler particles [4].

Ramish k.et.al, have study the effect of epoxy modifiers (Al_2O_3, SiO_2, TiO_2) on mechanical performance of epoxy/glass fiber hybrid composite. The results shown that mechanical properties like flexural strength, and flexural modulus are more in case of SiO_2 modified epoxy composite compare to other micro modifier. This is may be because of smaller particle size of silica compare to other. Alumina modified epoxy composite increase the hardness and impact energy compare to other modifiers [5].

2. Experimental Procedure

2.1. Materials

In our study, commercially available Al_2O_3 (45 nm), SiO_2 (38 nm), TiO_2 (47 nm) particles are used to modify the epoxy matrix. Nano fillers of Al_2O_3, SiO_2 and TiO_2 were purchased from nano Shell Company. Commercially available woven roving fabric E-glass fiber from the Tenax Company, England. The epoxy which is used was Euxit (50) base as the matrix from the (Al-Rakaez Building Materials) made in Egypt in the form of transparent viscous liquid at room temperature which is a thermally hardened polymers (Thermosets) with a density of (1.05 gm / cm^3)

2.2 Fabrication of Hybrid FRP Composite

There are three types of hybrid FRP composite with different fillers are fabricated using hand lay-up method. The volume percentage of epoxy, fiber, filler and hardener are fixed and designations of the composites are reported in Table -1. Where A, S and T indicate Al_2O_3, SiO_2 and TiO_2 modified FRP composite. Adding the powder intermittently into the mixture and stirring it for a period of (10-15) minutes to obtain homogeneity. A rise in the temperature of the mixture will result as an indication to the beginning of the interaction process. It is very important that the mixture must have a good viscosity for the purpose of protecting the particles from precipitation which may result in the heterogeneity of the mixture that leads to the agglomeration after hardening. Pouring the mixture into the mould, then putting the glass fiber mat into the mould and continuing of mixture pouring until it covers the entire mat. Pressing the mixture with an appropriate load. For the purpose of completing the process of hardening, finally is leaving the sample in the mould for a period of (24) hour at room temperature. Samples are then extracted from the mould and then heat treated in an oven at (60Ċ) for a period of (60) minutes [6]. This process is very important for the purpose of obtaining the best cross linking between polymeric chains, and to remove the stresses generated from the preparation process and complete the full hardening of the samples. Fig. 1 shows the shape of the prepared mould.

Table 1,
Designation and composition of composites

Designation of composites	Composition
A	Epoxy + 3% G.F + 2, 4 and 6 % Al_2O_3
S	Epoxy + 3 % G.F +2, 4 and 6% SiO_2
T	Epoxy+ 3% G.F+2, 4 and 6%TiO_2

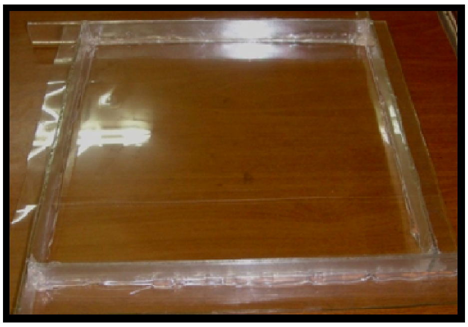

Fig. 1. The shape of the prepared mould.

3. Results and Discussion

3.1. XRD of Powder

The X-ray powder diffraction patterns are shown in Fig. (2).For three materials, all major peaks were assigned to the crystalline structure. Al_2O_3 was hexagonal structure, SiO_2 was cubic structure, and TiO_2 was tetragonal structure.

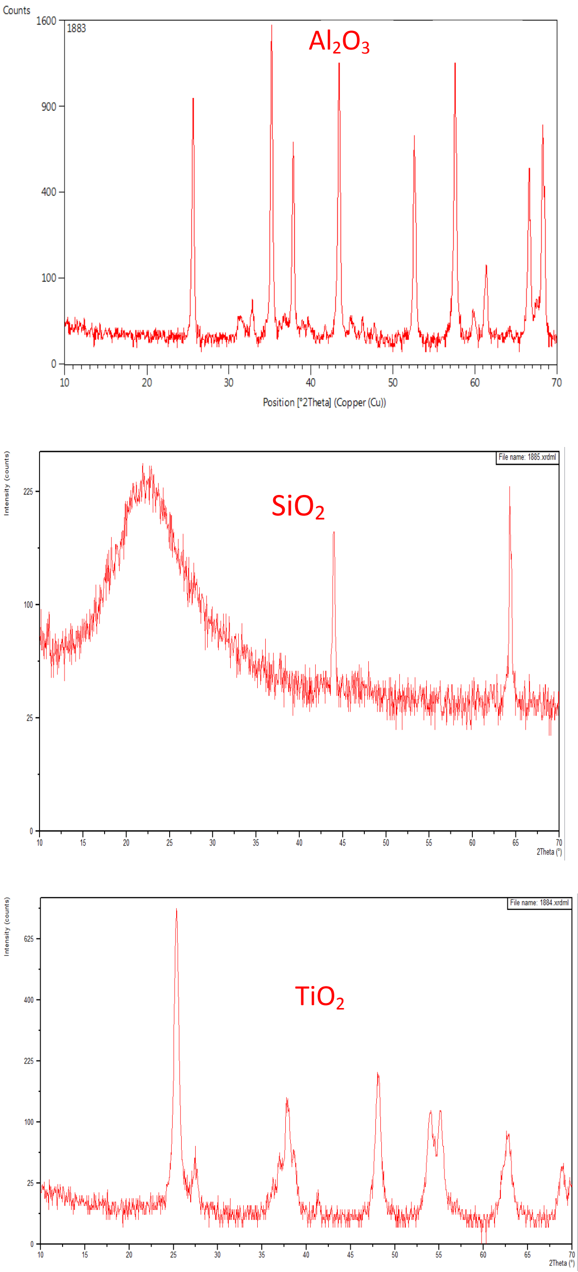

Fig. 2. The XED of nano powder.

3.2. Hardness (shore D)

This test is performed by using hardness (Shore D) and according to (ASTM DI-2240) standard at room temperature. Samples have been cut into a diameter of (40mm) and a thickness of (5mm) [7]. Table (2) shows the values of hardness for the prepared (Pure Epoxy, Epoxy +3% glass fiber and nano) composites.

Table 2,
Hardness of Prepared Composites.

Types of composites	hardness shore D
Ep	77
Ep +3% G.F	78
Ep + 3%G.F+2% SiO_2	81.5
Ep + 3%G.F+4% SiO_2	83.7
Ep + 3%G.F+6% SiO_2	84.8
Ep + 3%G.F+2% Al_2O_3	81.2
Ep + 3%G.F+4% Al_2O_3	83.2
Ep + 3%G.F+6% Al_2O_3	84.3
Ep + 3%G.F+2% TiO_2	80.5
Ep + 3%G.F+4% TiO_2	82.7
Ep + 3%G.F+6% TiO_2	83.9

From fig. (3) it is clear that there is a pronounced effect of the addition of 3% glass fiber volume fraction percents on the hardness of the material. This may be due to the fact that the hardness is generally considered to be a property of the surface therefore this behavior of hardness is expected. And can be seen from figure a pronounced effect of the addition of 3% glass fiber with 2%, 4%and 6% volume fraction from (nano powder) percents on the hardness of the material. It can be seen that the hardness increases with increasing volume fraction. Adding the filler particles will raise the materials hardness due to increasing in material resistance against the plastic deformation. Result had revealed that the hardness of pure epoxy alone was (77 shore D) compared to maximum value (84) at volume fraction of (6% SiO2) with particle size is (38nm). The reason of the increase in hardness is that SiO2 contains an elements harder than the pure epoxy that lead to an increase in hardness. These results become match with our work because the SiO2 have larger surface area and smaller particle size than (Al2O3and TiO2).

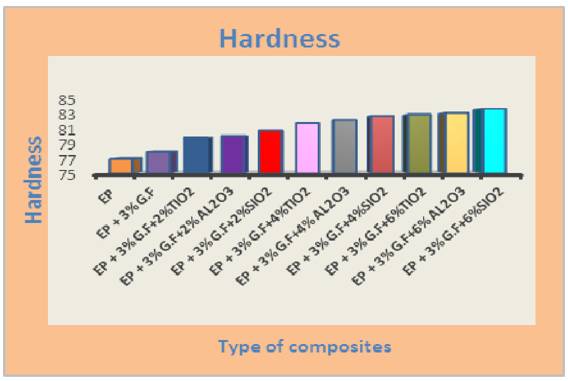

Fig. 3.hardness of papered composite.

3.3. Flexural Strength

This test is performed according to (ASTM D790) at room temperature. Samples have been cut into the dimensions (80*3.2*2.5) mm [8]. The flexural strength are calculated according to the equations [9]

$$F.S = \frac{3PL}{2bd^2} \quad \dots (1)$$

Where

F.S flexural strength (MPa).
p force at fracture (N).
L length of the sample (mm).
b thickness (mm).
d width (mm).

Table (3) shows the values of flexural strength for all prepared composites.

Table 3,
Flexural strength of prepared composites.

Types of composites	Flexural strength
Ep	149
Ep +3% G.F	158
Ep + 3%G.F+2% SiO_2	325
Ep + 3%G.F+4% SiO_2	349
Ep + 3% G.F+6% SiO_2	375
Ep + 3%G.F+2% Al_2O_3	310
Ep + 3%G.F+4% Al_2O_3	342
Ep + 3%G.F+6% Al_2O_3	362
Ep + 3%G.F+2% TiO_2	290
Ep + 3%G.F+4% TiO_2	337
Ep + 3%G.F+6% TiO_2	355

Fig.4.shows flexural strength of all prepared composites. It can be noted from this figure that the addition of 3% glass fiber with 2%, 4% and 6% volume fraction from nano powder has a significant effect on the flexural strength of the composite material. And, the flexural strength increases with increasing volume fraction and decreasing of the particle size. The flexural strength of pure epoxy reference was (149 MPa), and then an increasing was observed with increasing in volume fraction till it reached to its maximum value of (375 MPa) by the addition of (3% glass fiber) and volume fraction of (6% SiO2) with particle size is (38nm) which is (151%) higher than epoxy alone. These results match with the present because the SiO2 has particle size smaller than (Al2O3 and TiO2), this can be attributed to ductility of SiO2 which is reducing the brittleness of composite.

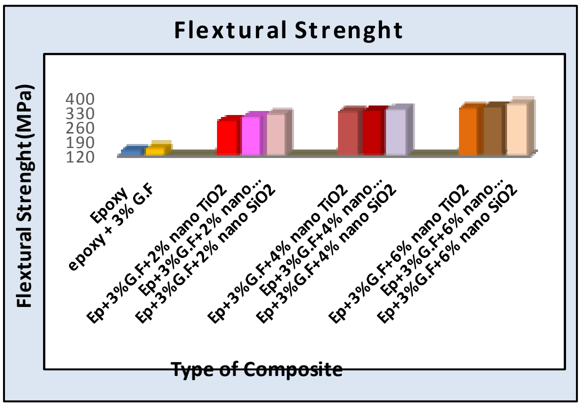

Fig. 4. Flextural strength of papered composite.

3.4. True Density

This test is performed according to (ASTM D792) standard at the room temperature [9].The samples were cut into a diameter of 40 mm and a thickness of 5 mm the measured density (ρt) is calculated from the method of immersion in water using the following relationship [10].

$$\rho t = (Wd / Ws - Wn) * D \quad \dots (2)$$

Where:

Pt Measured density or bulk density (gm/cm^3).
D Density of distilled water (1 gm/cm^3).
Wd dry weight of sample (gm).
Wn weight of the sample, a commentator and submerged with water (gm).
Ws weight of the sample is saturated with water (gm).

Table (4) shows the values of density for the prepared composites.

Table 4,
Density of prepared composites.

Types of composites	True density
Ep	1.05
Ep +3% G.F	1.080
Ep + 3%G.F+2% SiO_2	1.122
Ep + 3%G.F+4% SiO_2	1.155
Ep + 3% G.F+6% SiO_2	1.185
Ep + 3%G.F+2% Al_2O_3	1.130
Ep + 3%G.F+4% Al_2O_3	1.165
Ep + 3%G.F+6% Al_2O_3	1.197
Ep + 3%G.F+2% TiO_2	1.140
Ep + 3%G.F+4% TiO_2	1.178
Ep + 3%G.F+6% TiO_2	1.215

Fig.5 show the true density for prepared composites. In Fig. 5 can be seen the higher true density has been found to be for the specimen (epoxy +3%G.F+6%TiO2) due the TiO2 powder have density higher than individual density when compared with composite (Al2O3 and SiO2) nano Powder. Where the density of TiO2 (4.25 gm/cm3), Al2O3 (4.05 gm/cm3) and SiO2 (2.7 gm/cm3) .When comparing the value of true density nano composite with measured density of (pure Epoxy) can be seen higher than because the additions of reinforcement (TiO2, Al2O3, SiO2) nano powder that have higher density than matrix (pure epoxy).where density of pure epoxy (1.05 gm/cm3).

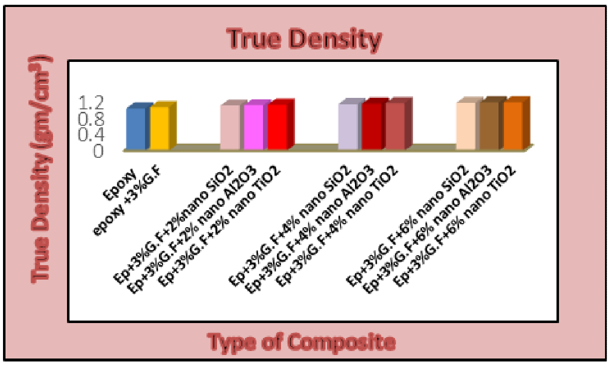

Fig. 5. True density of papered composite.

3.5. Water absorption

This test is performed according to (ASTM D 570) standard at room temperature [11]. Samples have been cut into a diameter of (40mm) and a thickness of (5mm). The mechanism of water absorption is explained to be the direct uptake and flow of water by capillary and transport along the reinforcement-matrix interface [12]. Water absorption percentage is calculated using (Archimedes base) according the following formula [13].

$$M(\%) = \frac{(mt - m_o)}{m_o} \times 100 \quad \ldots (3)$$

Where

M (%) water absorption percentage.

mo mass of specimen before immersion (g).

mt: mass of specimen after immersion for seven days (g).

Table (5) shows the values of water absorption for the prepared composites.

Table 5,
water absorption of prepared composites.

Types of composites	water absorption
Ep	0.120
Ep +3% G.F	0.195
Ep + 3%G.F+2% SiO_2	0.215
Ep + 3%G.F+4% SiO_2	0.313
Ep + 3% G.F+6% SiO_2	0.364
Ep + 3%G.F+2% Al_2O_3	0.240
Ep + 3%G.F+4% Al_2O_3	0.325
Ep + 3%G.F+6% Al_2O_3	0.378
Ep + 3%G.F+2% TiO_2	0.275
Ep + 3%G.F+4% TiO_2	0.340
Ep + 3%G.F+6% TiO_2	0.385

In Fig. 6 shows the water absorption of all prepared composites can be seen the specimen (epoxy +3%G.F) have higher water absorption than specimen (pure epoxy), the increasing water absorption percentage with increasing volume fraction of fiber depends on the rule of mixture theory where fiber have a higher water absorption percentage than specimen pure epoxy [14]. The water absorption attacked the fiber-matrix interface, causing de-bonding of the fiber and the matrix. The failures of the composite materials were due to voids [15]. And nano composites given higher water absorption percentage than specimen pure epoxy and specimen (epoxy +3%glass fiber) composites. the higher water absorption percentage of nano composite has been found to specimen (epoxy +3%G.F+6%TiO2) while the specimen (epoxy + 3%G.F+6% SiO2) have lower than specimen of (Al2O3 and TiO2) at the volume fraction (3%) of glass fiber and (6%) volume fraction of filler particles (nano powder), and the specimens (epoxy +3%G.F+2% TiO2), (epoxy +3%G.F+4% TiO2)have higher water absorption percentage while the specimen (epoxy + 3%G.F+2% SiO2), (epoxy + 3%G.F+4% SiO2) have lower than specimen of (Al2O3 and TiO2) at the volume fraction (3%) of glass fiber and (2%,4%) volume fraction of filler particles (nano powder).In this work the specimens of composite material filled with larger particles show a higher water absorption percentage when compared with the specimens of composite material filled with small particles because the saturation level of fillers matrix composition influenced by agglomeration that will affect the water absorption percentage of the composite material. The mean particle size of the (SiO2) is (38nm) while mean particle size of the (Al2O3) is (45 nm) and mean particle size of the (TiO2) is (48nm).

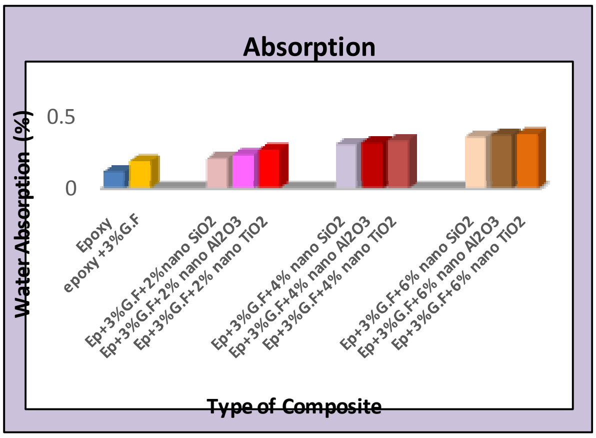

Fig. 6.water absorption of papered composite.

3. Conclusion

Non –reinforced pure Epoxy has lower physical and mechanical properties than (epoxy+3%glass fiber) composites and nano composites. The values of measured density are lower than nano composite with 3% glass fiber and 6% nano powder have the higher density when compared with other composites. Nano composite with (epoxy +3% glass fiber +6%TiO2) has the maximum density of (1.215) (gm/cm3) when compared with other composites. The values of water absorption of specimen (pure epoxy) lower than specimen (epoxy +3% glass fibers). Nano composite with 3% glass fiber and 6% nano powder have the higher water absorption when compared with specimen (pure epoxy) and specimen (epoxy +3% glass fibers) composites. Nano composite with (epoxy +3% glass fibers +6%TiO2) has the maximum water absorption of (0.385%) Result shows that the best hardness value was (84.8 shore D), Flexural strength (375MPa) at volume fraction of (3%glass fiber) with (6% SiO2).

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تأثير المساحيق النانويه على الخواص الميكانيكية والفيزيائية للمواد المركبة المدعمة بالالياف الزجاج

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الخلاصة

تم في هذا البحث تحضير مواد متراكبه بواسطة طريقة القولبة اليدوية ودراسة خصائصها. تتكون المواد المتراكبة من راتنج الايبوكسي كماده اساس و٣% كسر حجمي من ألياف الزجاج كمادة تقوية و ٢% و٤% و ٦% لمساحيق نانويه (اوكسيد الالمنيوم Al_2O_3 ، اوكسيد السليكون SiO_2 ، اوكسيد التيتانيوم TiO_2). فحص الصلاده ومقاومة الانحناء والكثافه والامتصاصيه للكشف عن قيمها لكل نوع من المواد المتراكبة النانويه. اظهرت النتائج ان الايبوكسي غير المقوى يمتلك خواص اقل من المواد المتراكبة . عند اجراء اختبارات الكثافة فان النتائج اظهرت بان الكثافة تزداد مع زياد الكسر الحجمي وامتصاصية الماء والصلادة ومقاومة الانحناء بانها تزداد مع زيادة الكسر الحجمي مع اصغر حجم حبيبي .